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NASA
Technical
Paper
3477

May 1994

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(NASA-TP-3477) USE OF A PITCH ADJUSTABLE FOOT RESTRAINT SYSTEM: OPERATOR STRENGTH CAPABILITY AND LOAD REQUIREMENTS (NASA. Johnson Space Center) 33 p

N94-33050

Unclas

H1/54 0008496

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Use of a Pitch Adjustable Foot Restraint System: Operator Strength Capability and Load Requirements

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National Aeronautics and
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Acronyms and Abbreviations

ABL	Anthropometry and Biomechanics Laboratory
ANOVA	Analysis of Variance
APAS	Ariel Performance Analysis System
DTO	Development Test Objective
FER	Force Effectiveness Ratio
ISSA	International Space Station Alpha
IVA	Intravehicular Activity
LESC	Lockheed Engineering & Sciences Company
NASA	National Aeronautics and Space Administration
TAF	Torque Application Fixture

Acknowledgments

This research was supported by Contract No. NAS9-18800 from the National Aeronautics and Space Administration and was conducted in the Anthropometry and Biomechanics Laboratory, Johnson Space Center, Houston, Texas. We wish to thank Boeing Aerospace and Harry Johnson at Grumman Space Systems for supplying the prototype foot plate hardware in support of these evaluations.

Summary

The zero-gravity (zero-g) environment creates a need for a proper human body restraint system to maintain a comfortable posture with less fatigue and maximize productivity. In addition, restraint systems must be able to meet the loading demands of maintenance and assembly tasks performed on orbit. The Shuttle's primary intravehicular astronaut restraint system is currently a foot loop design that attaches to flat surfaces on the Shuttle. This restraint system allows for variation in the mounting locations and for ease of ingress and egress. However, this design limits performance because it does not allow for elevation, pitch, or foot loop length adjustment. Several prototype foot restraint systems are being evaluated for use aboard International Space Station Alpha (ISSA) and the Space Shuttle. Previous evaluations on restraint systems have emphasized qualitative evaluations of restraint mechanisms but have not quantified the operator-induced loads on these systems. To fully define the loads a restraint system must be able to endure, both axial and moment loading on foot restraints needed to be evaluated.

The Anthropometry and Biomechanics Laboratory (ABL) initiated this study to quantify the maximum axial forces and moments that would be induced on a foot loop type of restraint while operators performed a torque wrench task. In addition, the foot restraint pitch angle was altered to quantify the effect this had on the foot restraint loading as well as to determine any differences in the force that could be produced at the torque wrench.

Results indicate that the greatest forces into the torque wrench and into the foot restraint system occur while the operator performs an upward effort. The force mean values ranged from approximately 300 to 700 N. The absolute maximum force value observed in this study on the foot restraint system was approximately 1180 N with the maximum moment of 160 Nm.

Overall, this study did not see any significant difference in the force that operators could place on the torque wrench or forces imparted to the foot restraint system due to the pitch orientation of the foot restraint. Thus in a work environment in which handholds are available, no significant influence of the pitch angle on forces imparted to the restraint system existed.

1.0 INTRODUCTION

The zero-g environment creates a need for a proper human body restraint system to maintain a comfortable posture with less fatigue and maximum productivity[1]. In addition, restraint systems must be able to meet the loading demands of maintenance and assembly tasks performed on-orbit. Previous studies on restraint systems have emphasized qualitative evaluations of restraint mechanisms but have not quantified the operator-induced loads on these systems[2].

Several foot restraint systems are under development for ISSA and the Space Shuttle. One general ISSA design uses a seat track mounting scheme and is adjustable to meet various demands. The system uses a foot plate in which the height and pitch is adjustable. The restraint mechanism also incorporates a means of tightening the toe loop to the foot. This development hardware has been flown in a similar design as development test objective (DTO) 0655 on STS-50 and STS-47. The DTO was flown to evaluate characteristics like ingress/egress, equipment adjustability and long-term fatigue, but did not instrument the restraint systems to evaluate the nominal or maximum loading values exerted on orbit.

An investigation that partially addressed the issue of quantifying loads placed on foot restraints was an evaluation to determine the affect that tool orientation had on the strength individuals displayed while performing a torquing task[3]. While the emphasis of this study was on the effect of tool orientation on strength capability, the report also included the axial loads imparted to the foot restraint but did not document the moments. However, to fully define the loads a restraint system must be able to endure, both axial and moment loading need to be evaluated.

The ABL initiated this study to quantify the maximum axial forces and moments that would be induced on a foot loop type of restraint while operators performed a torque wrench task. In addition, the foot restraint pitch angle was altered to quantify the effect this had on the foot restraint loading, as well as determine any differences in the force that could be produced at the torque wrench.

2.0 METHOD

2.1 Apparatus

An aluminum test stand was equipped and instrumented to conduct the study (figure 1). A photo of the overall test stand has been included in appendix B. The test stand had a foot restraint system at the base as well as a handhold and torquing fixture on the upper panel. The aluminum test stand was designed to accommodate the mounting of two force plates for recording the torque wrench and foot restraint forces. One force plate was mounted horizontally to accommodate the mounting of the foot restraint and the other force plate was mounted vertically for the torque application fixture (TAF).

The force plates used in this investigation were Kistler Instrumente AG force plates (Model Z14248). The force plates provided three components of force and torque that is applied to them. The surface dimensions of the force plates are 40 cm by 60 cm. The force plates were mounted on 1.27-cm (1/2-inch) aluminum plates attached to the aluminum test stand. Amplification of the force plate's analog signals was achieved by a Kistler Instrumente AG charge amplifier (Model 9865 A1 Y28) prior to the conversion and subsequent storage of digital values in a data acquisition system. The data acquisition system used for this evaluation was the Ariel Performance Analysis System (APAS). A sampling rate of 250 Hz was used. The force plate, charge amplifier, and APAS were all calibrated prior to data collection.

The TAF (figure 2) was used to achieve six torque application directions (up, down, in, out, right, and left) used to evaluate the maximum foot restraint loading. The TAF consisted of five nodes each oriented along an axis as defined in figures 1 and 2. The wrench used in these evaluations had a handle length of 22.86 cm (9 inches). Table 1 summarizes the wrench placement by specifying the node the socket was placed on and the axis alignment of the wrench handle. A non-instrumented handhold was placed directly to the side of the TAF (figure 1).

The foot restraint system consisted of a foot plate clamped to two cross bars (figure 4). Figure 3 depicts the support hardware and adjustment hardware for the foot plates. The hardware was designed to allow pitch adjustment of the restraint in 5° increments, through the use of pip pins.

Two Quasar camcorders (model VM-37) were used for the general video recording of the experiment.

Table 1. Torque Wrench Location and Handle Alignment

Operator Torque Motion	Socket Node	Torque Wrench Handle Alignment
Up	- Y	- Z
Down	- Y	- Z
In	- X	- Y
Out	- X	- Y
Left	- Z	+ X
Right	- Z	+ X

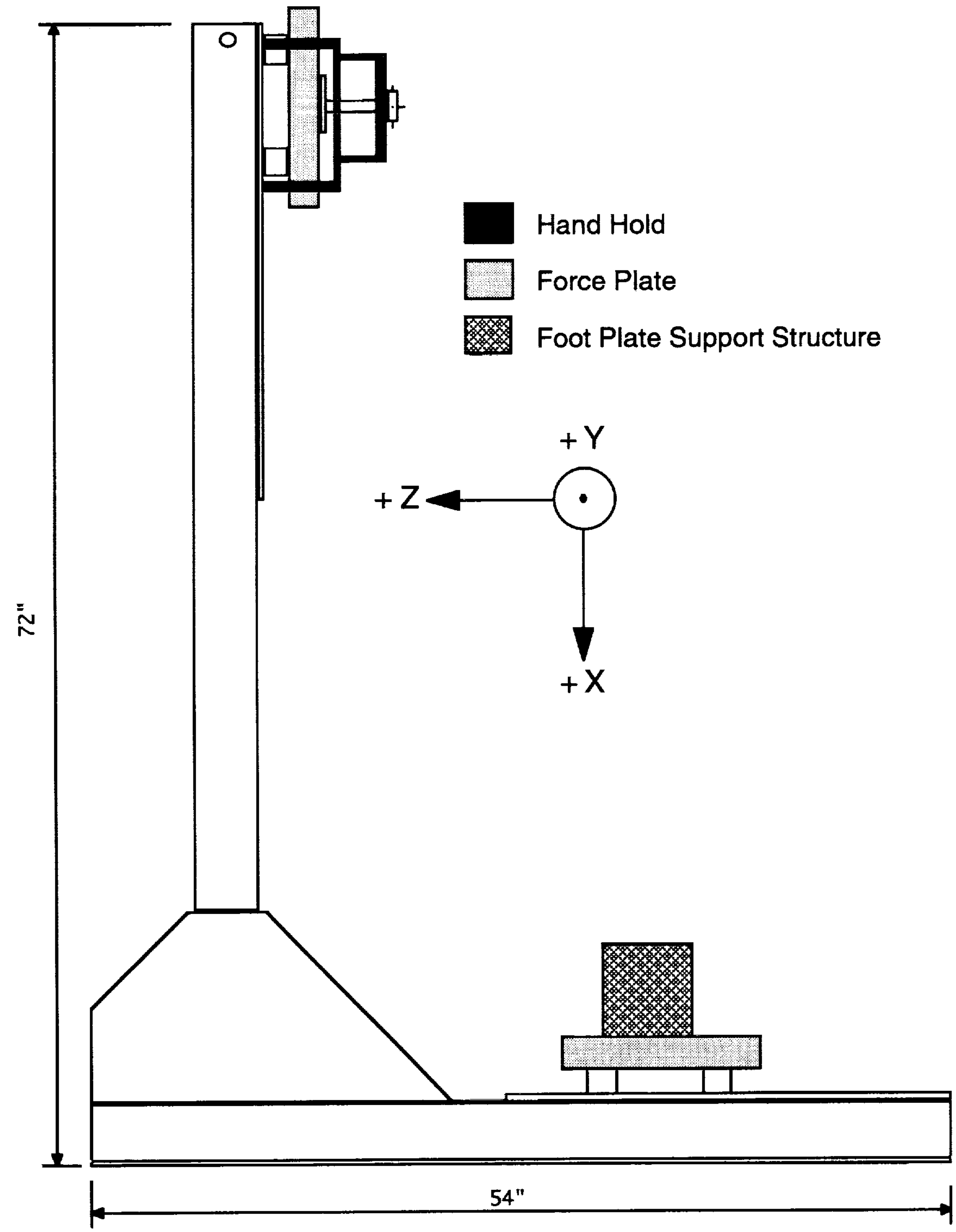


Figure 1. Test stand for force plate mounting (side view).

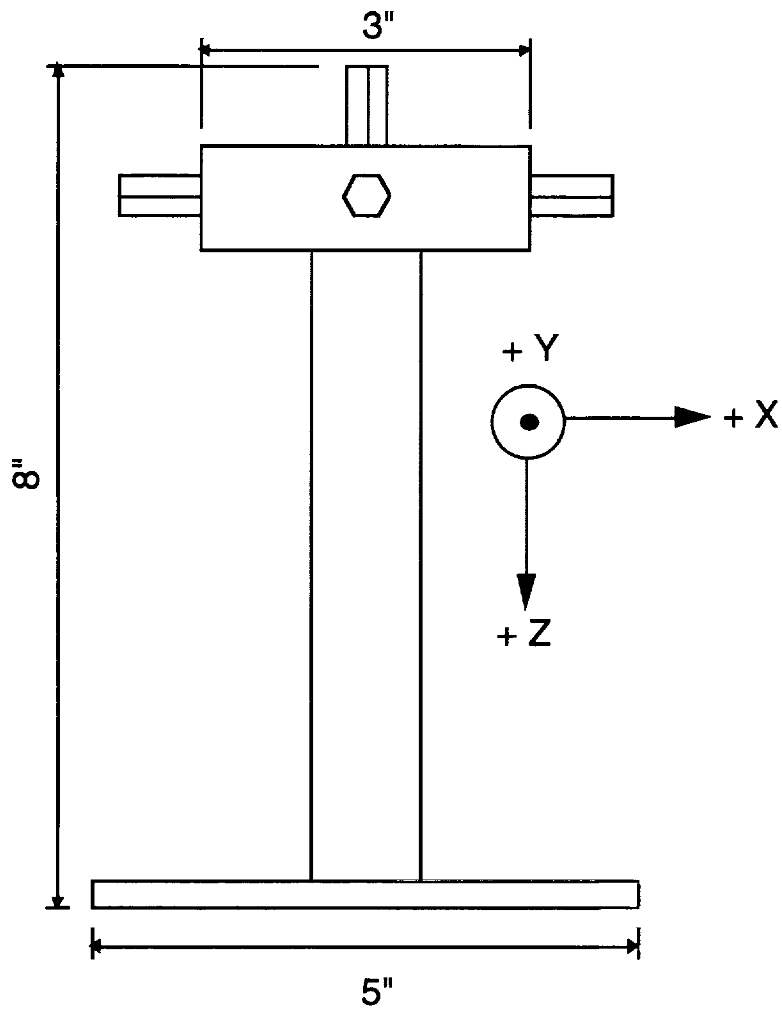
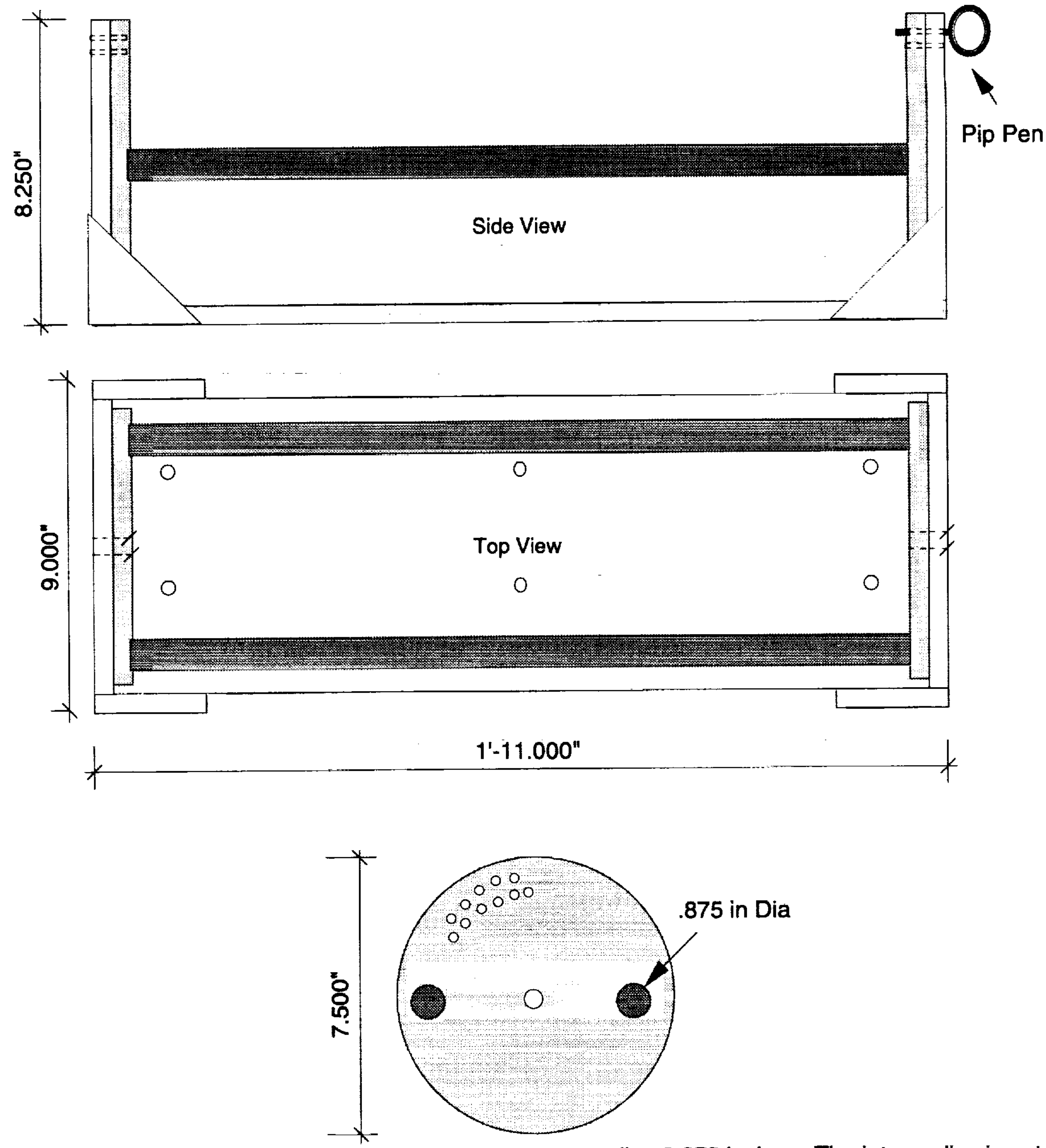


Figure 2. Torque application fixture (side view).



Small 1/4 inch pin holes inter radius 2.75 inches and outer radius 3.375 inches. The inter radius in settings 0^{o}, 10^{o}, 20^{o}, 30^{o}, 40^{o}, and 50^{o} while the outer radius is 5^{o}, 15^{o}, 25^{o}, 35^{o}, and 45^{o} settings.

Figure 3. Foot loop plate mounting structure.

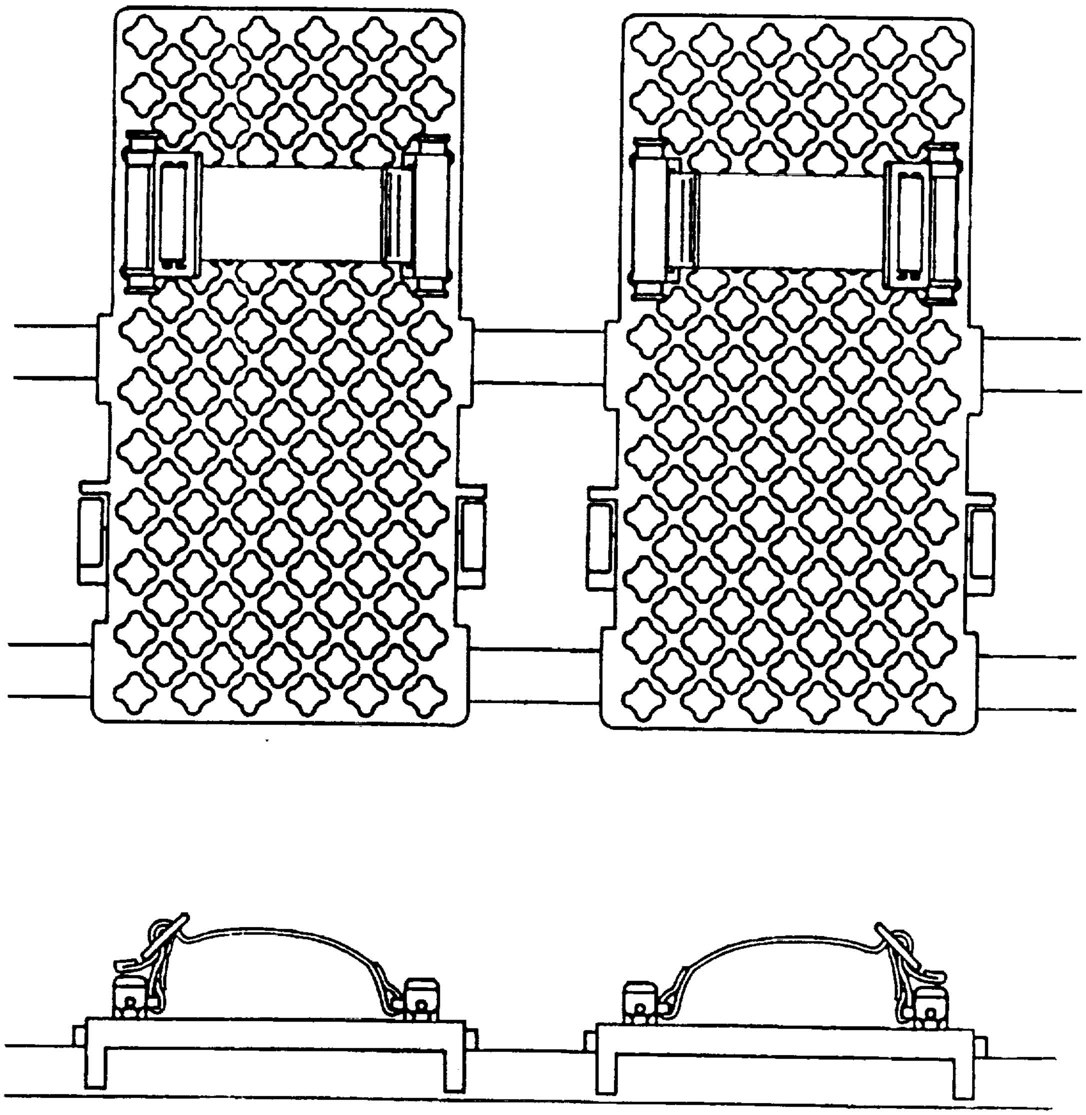


Figure 4. Foot plate and loop design.

Note: Foot plate drawing was developed from drawing # G11F5925 Grumman Aerospace Corporation

2.2 Subjects

Four subjects were used in these evaluations. One subject was female and three were male. Table 2 presents the height and weight of the subjects and summarizes the relative percentiles of the subjects based upon stature using the Man Systems Integration Standards[4]. Percentiles were calculated using a normal population based on the 5th, 50th and 95th percentile measurements from each of the sources to determine the appropriate percentile.

Additional sources could also be used to determine the subject percentiles, including the Anthropometry Astronaut Candidate Database[5] or the Anthropometry Survey of U.S. Army Personnel[6].

Table 2. Subject Stature Percentiles

Subject	Gender	Weight (kg)	Stature (cm)	MSIS
Subject 1	Male	71.2	172.7	12.1%
Subject 2	Male	88.4	177.8	36.4 %
Subject 3	Female	59.0	167.6	98.47 %
Subject 4	Male	72.6	167.6	2.31 %

2.3 Procedure

This investigation used a ground-based evaluation to familiarize subjects with the task and terminology. Data collection was performed in zero g aboard NASA's KC-135. The KC-135 aircraft flies a parabolic path that creates a period of zero g approximately 23 seconds long followed by a 2-g pull up and pull out (see appendix A). This evaluation used 60 parabolas on two separate days and had two subjects per flight. Subjects alternated performing the torquing tasks in 5-parabola blocks to minimize fatigue. Each parabola consisted of performing maximum efforts in four of the six directions. Each block of five parabolas consisted of performing the maximum torquing in the same four directions of effort while changing the inclination angle of the foot restraint in 10° increments. A non-instrumented handhold was used by the left hand directly beside the TAF.

The change in inclination angle was always performed in ascending or descending order at 5°, 15°, 25° and 35° positions. Efforts were made to counterbalance the conditions (direction of effort and ascending or descending order of inclination angle). The fifth parabola in each block was used to make up any trials that were lost during the data collection. If the first four trials were completed without any problems than the next subject began and the fifth parabola was saved for use later in the flight.

2.3.1 Data Analysis

Processing of the data consisted of an initial step of getting the maximum force and moments seen during each effort. After this initial step, a single data set was created of the greater value of the two efforts in each condition performed by each subject. The next step was to convert the moment values from the force plate reference point to the foot plate reference point. This was necessary because the initial data collection references all moments with respect to an origin that is 54 mm back into the plate from the center surface point on the Kistler force plate. The referenced point used with the restraint system is a point in the center of the two support poles for the foot restraints and aligned with the pitch axis. Once this conversion was performed, the final data set was achieved.

Data analysis for this investigation includes force values observed on the torque wrench and on the restraint system. Each trial was performed twice by the four subjects and the maximum value for each subject was used for the data reduction. An Analysis of Variance (ANOVA) was then performed to determine if any statistical significance exists. Post hoc analysis was performed using the Scheffe test at a significance level of .05 to determine what the differences were between conditions.

3.0 RESULTS

3.1 Numerical Data

Numerical data on the amount of force generated at the torque wrench handle are presented in table 3. The numerical data from the foot restraint is presented in table 4 and table 5. The data presented are the mean and standard deviation of the four subjects' maximum efforts. Table 6 depicts the absolute maximum and minimum values observed across all subjects. Data are presented within this report with force in Newtons (N) and moments in Newton meters (Nm). Note that 1 N = 4.4 lb and 1 Nm = 1.36 ftlb.

In general, subjects could impart the greatest force on the torque wrench in the down and up directions with the upward direction being slightly larger than the downward direction. In correspondence to this operator effort, the foot restraint system had the greatest load induced on it during the upward effort of the operator. The greatest average moments were 117.1 Nm around the Y axis and 118.2 Nm around the Z axis.

The only statistically significant difference that was observed based on the difference in pitch angle occurred for the Z force at the foot restraint system between the 5° and 35° positions during an outward effort.

Table 3. Torque Wrench Numerical Force (N) Data

Direction of Effort	Angle	X Mean	X St Dev	Y Mean	Y St Dev	Z Mean	Z St Dev
Down	5	480.9	90.7	109.8	47.1	-8.0	74.7
	15	464.0	126.7	80.9	28.0	-24.0	64.4
	25	485.8	149.3	101.8	53.8	-26.2	57.3
	35	468.9	128.4	51.6	26.7	5.8	66.7
Up	5	-666.7	196.0	101.8	42.2	181.8	91.6
	15	-662.2	178.7	104.9	31.1	140.0	76.9
	25	-617.8	126.7	95.1	64.9	164.4	64.0
	35	-644.4	218.7	74.2	24.4	163.6	77.8
In	5	-212.4	38.2	41.3	79.6	305.3	62.2
	15	-208.0	86.7	90.7	52.0	284.9	60.4
	25	-223.6	128.0	22.7	48.0	303.6	68.9
	35	-135.1	73.8	28.4	87.6	297.8	58.7
Out	5	47.1	92.9	96.9	112.0	-364.0	145.8
	15	55.6	155.6	176.0	20.0	-382.2	149.8
	25	38.7	75.1	158.7	49.8	-368.0	141.8
	35	31.6	44.0	81.3	29.8	-322.7	108.9
Left	5	-61.8	52.9	357.3	104.9	55.6	34.7
	15	5.8	96.9	347.1	68.9	87.6	46.7
	25	-16.9	88.4	367.1	78.2	101.8	32.0
	35	50.7	61.3	313.8	52.4	51.1	74.7
Right	5	-30.7	56.9	-410.7	140.4	-118.7	83.6
	15	-12.4	85.8	-455.6	49.3	-208.4	52.0
	25	20.9	92.0	-404.0	85.3	-155.7	76.4
	35	-66.2	12.9	-384.0	131.1	-168.0	98.2

Table 4. Foot Restraint Numerical Force (N) Data

Direction of Effort	Angle	X Mean	X St Dev	Y Mean	Y St Dev	Z Mean	Z St Dev
Down	5	-467.1	32.9	-64.0	36.0	105.3	16.9
	15	-492.9	121.8	-54.2	13.3	92.4	18.2
	25	-475.6	111.6	-56.4	19.6	80.0	27.6
	35	-465.8	80.0	-67.1	14.7	87.1	17.8
Up	5	863.1	290.7	-24.9	42.7	-160.0	87.1
	15	812.4	285.8	-28.9	11.1	142.2	51.6
	25	898.2	325.8	-4.9	54.7	-120.0	74.7
	35	848.0	331.1	13.3	43.1	-128.9	73.8
In	5	291.1	26.7	22.2	44.0	-97.8	24.0
	15	259.1	86.7	51.1	13.8	-88.9	16.0
	25	315.1	76.0	54.2	35.6	-120.0	32.4
	35	240.4	44.4	16.0	53.3	-97.8	24.9
Out	5	121.8	142.7	-76.4	40.0	51.1	10.2
	15	120.9	136.0	-24.9	44.4	3.6	52.9
	25	187.1	87.6	-71.1	15.1	-20.9	60.4
	35	174.2	37.3	-72.9	52.9	-57.8	16.9
Left	5	173.3	85.8	-95.1	36.4	-25.8	16.9
	15	73.8	124.4	-80.9	30.7	3.1	51.6
	25	6.7	163.1	-79.1	31.6	-88.9	140.9
	35	44.4	84.9	-75.1	28.0	5.3	44.4
Right	5	12.0	83.6	77.8	20.0	33.3	42.7
	15	-24.9	103.1	62.7	17.8	21.3	32.9
	25	32.0	128.0	54.2	23.6	-32.9	94.2
	35	102.2	32.0	43.1	48.4	14.7	38.7

Table 5. Foot Restraint Numerical Moment (Nm) Data

Direction of Effort	Angle	Moment X Mean	Moment X St Dev	Moment Y Mean	Moment Y St Dev	Moment Z Mean	Moment Z St Dev
Down	5	23.6	10.6	23.0	11.0	9.1	21.6
	15	18.0	5.8	16.5	5.6	6.2	22.2
	25	14.2	6.1	-9.6	27.8	13.8	11.0
	35	23.7	8.0	-3.9	16.5	15.0	11.8
Up	5	24.7	21.7	45.7	98.2	77.7	7.5
	15	7.7	25.1	58.4	80.8	62.4	11.3
	25	36.2	19.1	62.2	88.4	63.0	45.7
	35	10.7	7.3	53.7	117.1	50.2	49.3
In	5	63.6	28.1	-27.1	37.7	14.9	70.8
	15	60.2	25.9	-2.8	45.0	0.5	53.0
	25	30.2	77.0	-29.8	57.2	-13.6	65.6
	35	64.0	33.1	-56.9	20.2	-26.7	31.0
Out	5	-54.2	15.7	66.6	16.4	38.5	52.5
	15	-62.4	13.8	23.7	58.2	25.9	24.1
	25	-35.2	78.1	10.7	60.2	47.9	29.7
	35	-68.1	13.8	12.3	43.5	39.7	53.8
Left	5	45.6	26.3	47.0	40.8	118.2	52.1
	15	28.3	38.2	22.1	45.6	84.7	49.9
	25	42.4	34.8	-3.5	24.3	79.9	31.7
	35	29.7	32.8	13.7	21.3	70.2	27.7
Right	5	-18.4	74.6	24.8	11.0	-61.0	30.5
	15	-54.1	10.4	1.6	37.3	-50.2	30.0
	25	-59.2	22.2	-24.4	10.0	-52.5	25.2
	35	-59.7	19.9	-19.0	47.6	-37.7	70.4

Table 6. Absolute Maximum and Minimum Data

Location and Direction	Maximum			Minimum		
	Angle	Condition	Value	Angle	Condition	Value
Tool Force X	25	Down	642.3	35	Up	-857.9
Tool Force Y	5	Left	455.1	5	Right	-544.8
Tool Force Z	5	In	370.7	15	Out	-570.3
Foot Force X	25	Up	1181.4	25	Down	-593.4
Foot Force Y	5	Right	90.3	5	Out	-135.5
Foot Force Z	5	Down	124.4	25	Left	-289.5
Moment X - Foot	35	In	92.0	25	Out	-106.7
Moment Y - Foot	5	Up	145.7	5	Up	-88.0
Moment Z - Foot	5	Left	159.9	35	Right	-92.1

3.2 Graphical Presentation of the Data

Graphical presentations of the force, torque and moment data are presented in figures 5-7. Each figure compares the equal and opposite directions of effort; down and up, in and out, and left and right. A visual representation of the orientation of the tool for the specific pair of efforts is also included with the axis designation. The notation used in the graphs is FX, FY and FZ represent the forces (in Newtons) seen at the foot restraint. MX, MY and MZ are the moments (in Newton Meters) that were observed on the foot restraint. HX, HY and HZ are the forces (in Newtons) imparted by the subjects hand on the TAF.

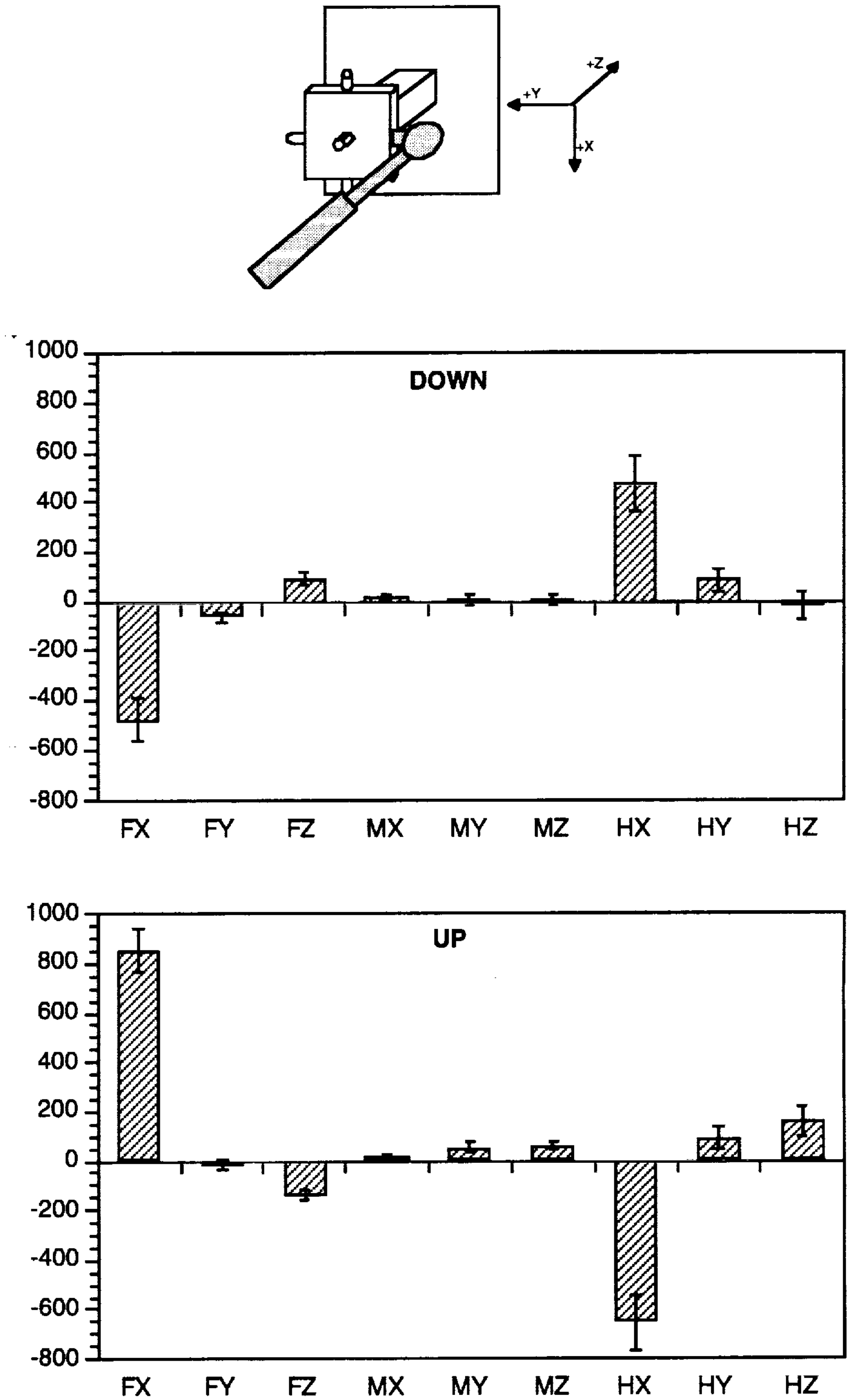


Figure 5. Graphical representation of down and up efforts.

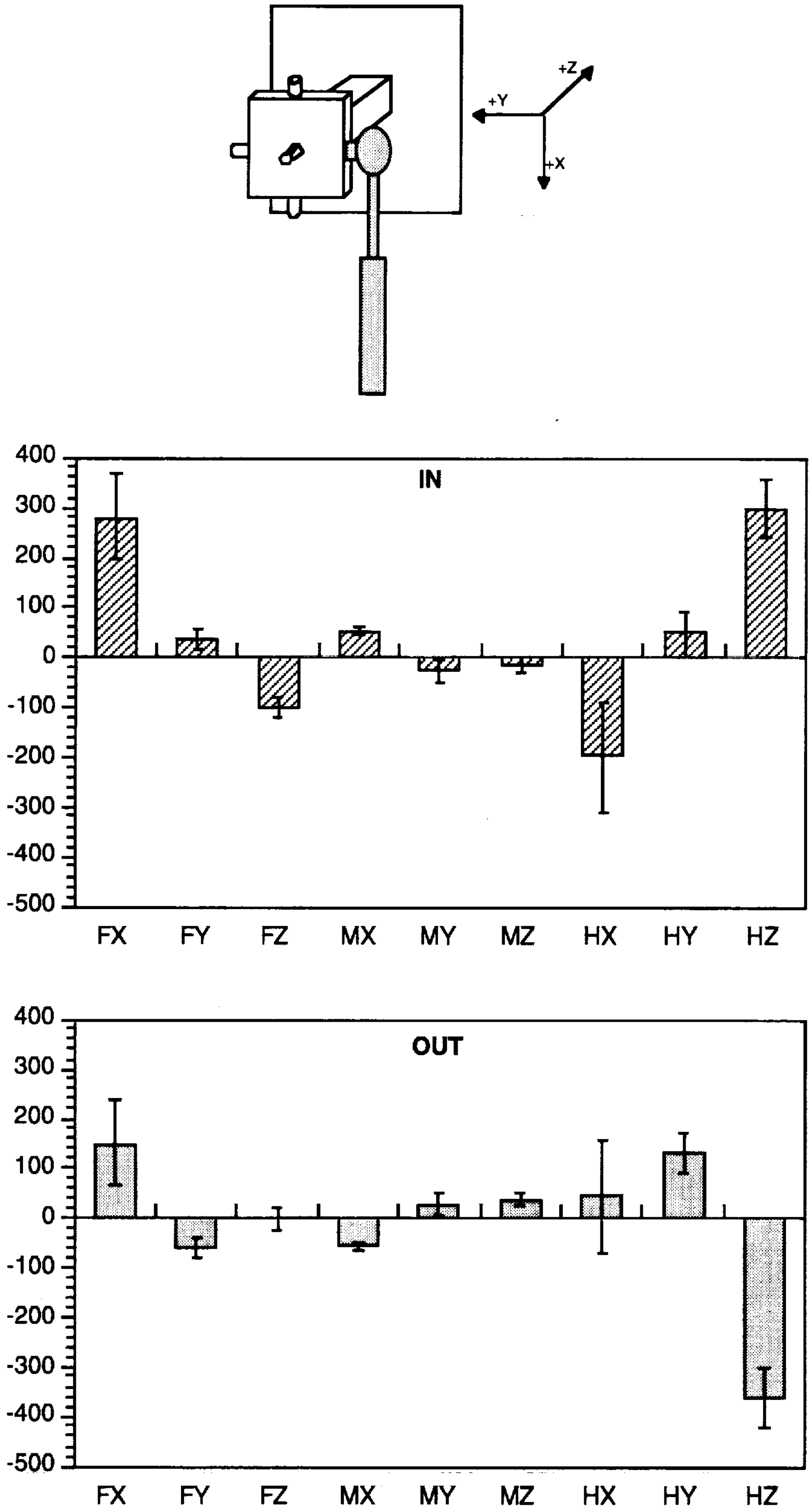


Figure 6. Graphical representation of in and out efforts.

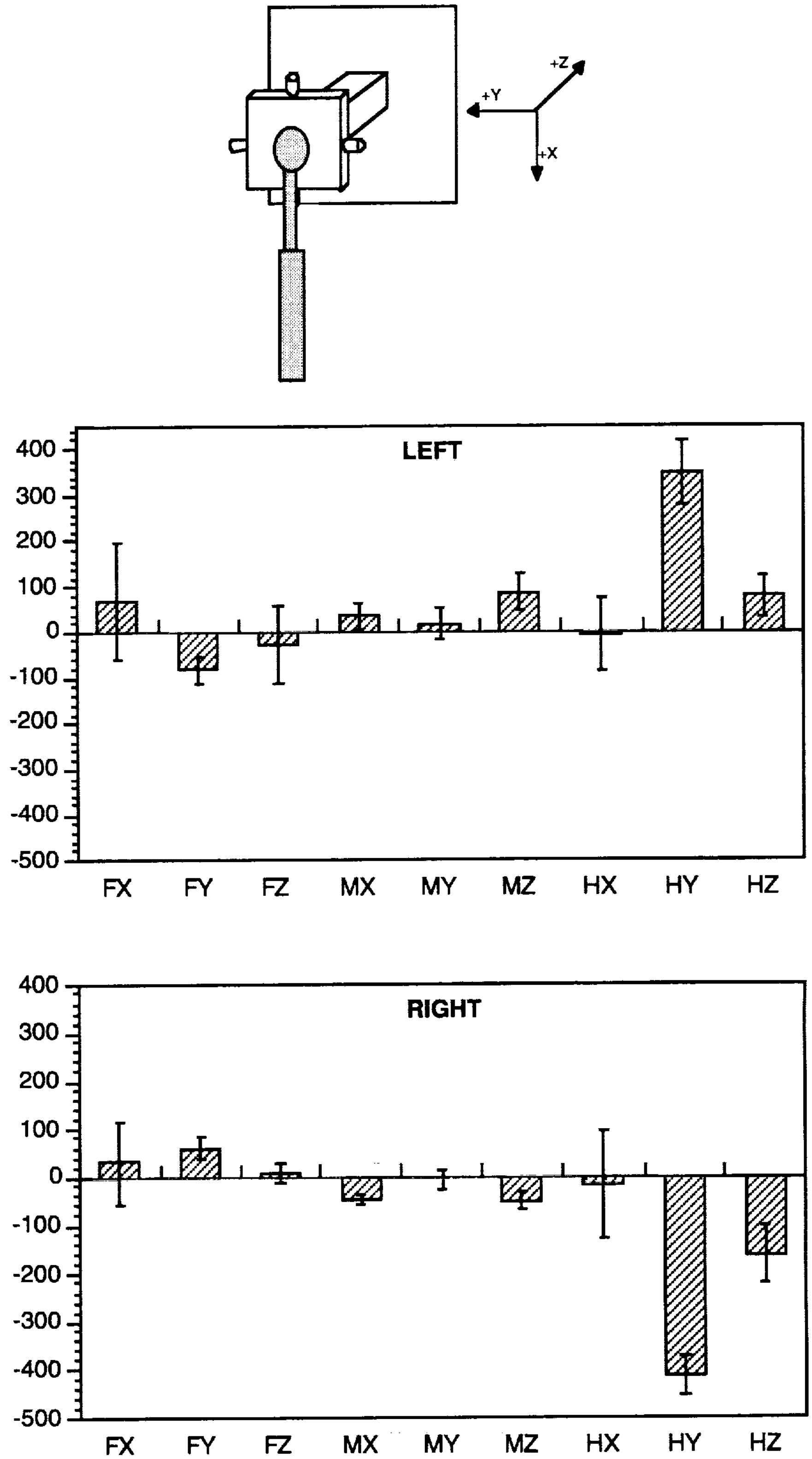


Figure 7. Graphical representation of left and right efforts.

3.3 Force Effectiveness

A force effectiveness ratio (FER) was defined as the ratio of the force on the tool in the applied direction to the square root of the sum of the squares of the peak forces in the X, Y, and Z directions:

$$FER = \frac{F_{applied}}{\sqrt{F^2_{x\,peak} + F^2_{y\,peak} + F^2_{z\,peak}}}$$

This parameter ranges from zero to one, and is an indication of how much of the subjects' total effort actually went into performing the desired task. A value of 1.0 meant that all of the force was applied in the intended direction; likewise a value close to 0.0 meant that no force was applied in the intended direction. Note that the peak of each component of force was used to calculate the FER and that these individual peaks did not necessarily occur at the exact same time. Values for FER for the test conditions are listed in table 6. The statistical analysis showed that no significant differences existed in the FER ratio due to pitch angle. Analysis did reveal that the inward motion was different from all other motions. The outward motion was also found to be significantly less than a down effort. The post hoc analysis was performed using Scheffe test at 5%. The data are also presented graphically in figure 8.

The force effectiveness ratio supplies information to help an operator understand the advantages of the specific body positions. Hence, because the zero-g environment allows positioning of an operator in any orientation toward a work area, the FER ratio information can be used to orient the operators in the most efficient manner for a particular task.

Table 7. Force Efficiency Ratio Data

Direction of Effort	Angle	FER Mean	FER St Dev	Average Mean	Average St Dev
Down	5	.965	.014		
	15	.976	.009		
	25	.968	.019		
	35	.982	.017	.973	.015
Up	5	.956	.020		
	15	.966	.015		
	25	.954	.022		
	35	.964	.011	.962	.017
In	5	.788	.095		
	15	.757	.148		
	25	.787	.142		
	35	.862	.108	.799	.123
Out	5	.892	.062		
	15	.848	.077		
	25	.866	.115		
	35	.955	.027	.890	.070
Left	5	.972	.017		
	15	.946	.024		
	25	.936	.026		
	35	.946	.009	.950	.019
Right	5	.948	.015		
	15	.901	.022		
	25	.917	.052		
	35	.884	.092	.913	.045

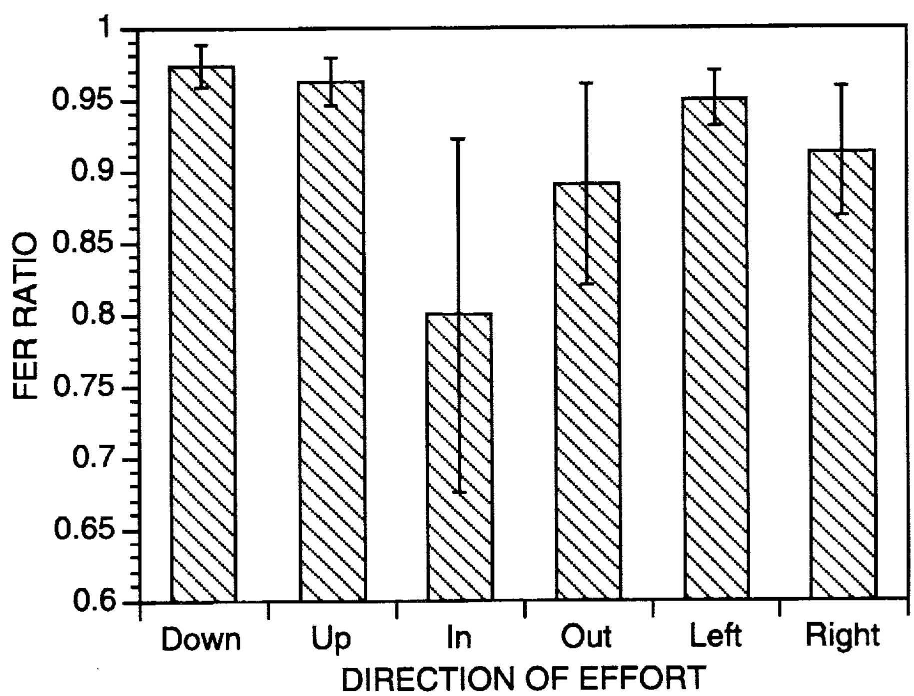


Figure 8. Graphical representation of FER ratio data.

4.0 DISCUSSION

The objectives of this investigation were to quantify the maximum forces and moments that would be induced on a foot restraint during a torque wrench task while using a toe loop foot restraint. As part of this evaluation, an effort to quantify the influence of foot restraint pitch angle on the maximum loads induced on the foot restraint and the maximum torques produced on the torque wrench was also incorporated.

The forces were greatest on the torque wrench and on the foot restraint system when the operator was performing an upward effort. The mean force values ranged from approximately 300 to 700 N. The absolute maximum force value observed in this study on the foot restraint system was approximately 1180 N with a maximum moment of 160 Nm.

Overall, no significant difference existed in the force the operator could place on the torque wrench or in the forces imparted to the foot restraint system due to the pitch orientation of the foot restraint.

The force effectiveness ratio did reveal that the inward motion was less efficient than all other motions. The outward motion was also found to be significantly less efficient than a down effort.

5.0 CONCLUSION

This study quantified the maximum forces and moments that operators induced on a toe loop foot restraint during a torque wrench task. The evaluation included quantifying the influence of foot restraint pitch angle on the basis of maximum loads induced on the foot restraint and the maximum force produced on the torque wrench.

This investigation supplies design information to foot restraint designers that are addressing tasks requiring high loads. In addition, this study supplies information on what the crew members' maximum capabilities would be for torquing tasks or for tasks performing the same motions. This information will assist in setting design specifications so the crew members' capabilities are not exceeded as well as to ensure that hardware and support structure will not fail.

While the results indicated that the pitch angle had no significant effect, this result might largely be due to the use of the alternate load-bearing path, a non-instrumented handhold, that was used by the operators during this task. The handhold was used in this study because it created a realistic scenario for maintenance-oriented tasks. The handhold did not allow the foot restraint to be in its worst-case loading condition in which the restraint is the sole load-bearing structure.

It was also observed that the forces seen in this study were within the requirement documentation listed in NASA-STD-3000/Vol. 1/Revision A/Section 11. However, requirements listed for a single foot restraint addresses only two values, negative X axis on the foot restraint (minimum 445N, 100 lb) and the X moment (minimum 200 Nm, 150 ftlb).

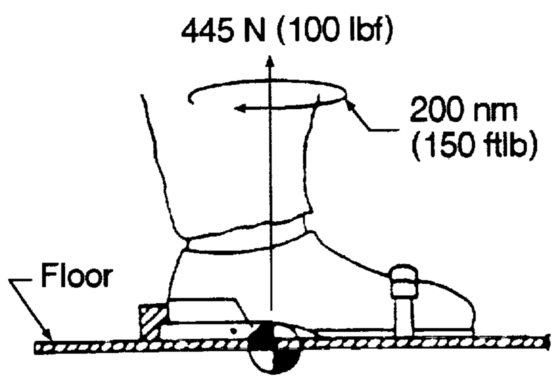


Figure 9. Body restraint design requirements.

Derived from NASA-STD-3000/Vol. 1/Rev. A, figure 11.7.2.3.2.3-1 IVA Foot Restraint Load Limits

This information is based on the assumption that the foot plate is secured to the floor while most of the developing foot restraint hardware has the capability to be elevated above the floor to accommodate a wide range of astronaut sizes. In this investigation, the loads associated with the negative X axis and the X moment were not the directions of maximum axial or moment loading. Thus the requirements within NASA-STD-3000 does not address the other axial direction and moment conditions. Because of the elevation of the foot restraints, the floor is not the load bearing structure and thus the foot restraint system itself must be able to withstand loading in all directions. It also does not address the common condition with the developing restraint systems of both feet being used as a single restraint system rather than designating loads for a single foot.

For this dual foot restraint system the maximum loading observed was:
+X axis = 1181.4 N (≈270 lb), -X axis = 593.4 N (≈135 lb),
+Y axis = 90.3 N (≈21 lb), -Y axis = 135.5 N (≈31 lb),
+Z axis = 124.4 N (≈28 lb), -Z axis = 289.5 N (≈66 lb),
Moment around X axis = 106.7 Nm (≈79 ftlb)
Moment around Y axis = 145.7 Nm (≈107 ftlb)
and Moment around Z axis = 159.9 Nm (≈118 ftlb)

6.0 RECOMMENDATIONS

In this investigation a dual foot restraint system was used to quantify the maximum forces and moments that would be induced on a foot restraint during a torque wrench task while using a toe loop foot restraint. Future evaluations should include the evaluation of a single foot design to verify the loading conditions for all axis and moment conditions. In addition, a dual foot restraint should be evaluated as the sole load-bearing structure during some simulated high load inducing maintenance tasks. An investigation of this nature would remove any effect the non-instrumented handhold had on the loads seen at the foot restraint, thus providing a worst-case scenario for comparison to the data presented within this report.

It is also recommended that NASA-STD-3000/Vol. 1 be revised to include loading requirements for all loading conditions taking into account the need for specific requirements for dual foot restraint systems. The recommended loading requirements for a dual foot restraint system should be:

+X axis = 1210 N (275 lb), -X axis = 660 N (150 lb),
±Y axis = 445 N (100 lb), ±Z axis = 445 N (100 lb)
Moment around X axis = ± 200 Nm (150 ftlb)
Moment around Y axis = ± 200 Nm (150 ftlb)
and Moment around Z axis = ± 200 Nm (150 ftlb)

7.0 REFERENCES

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APPENDIX A

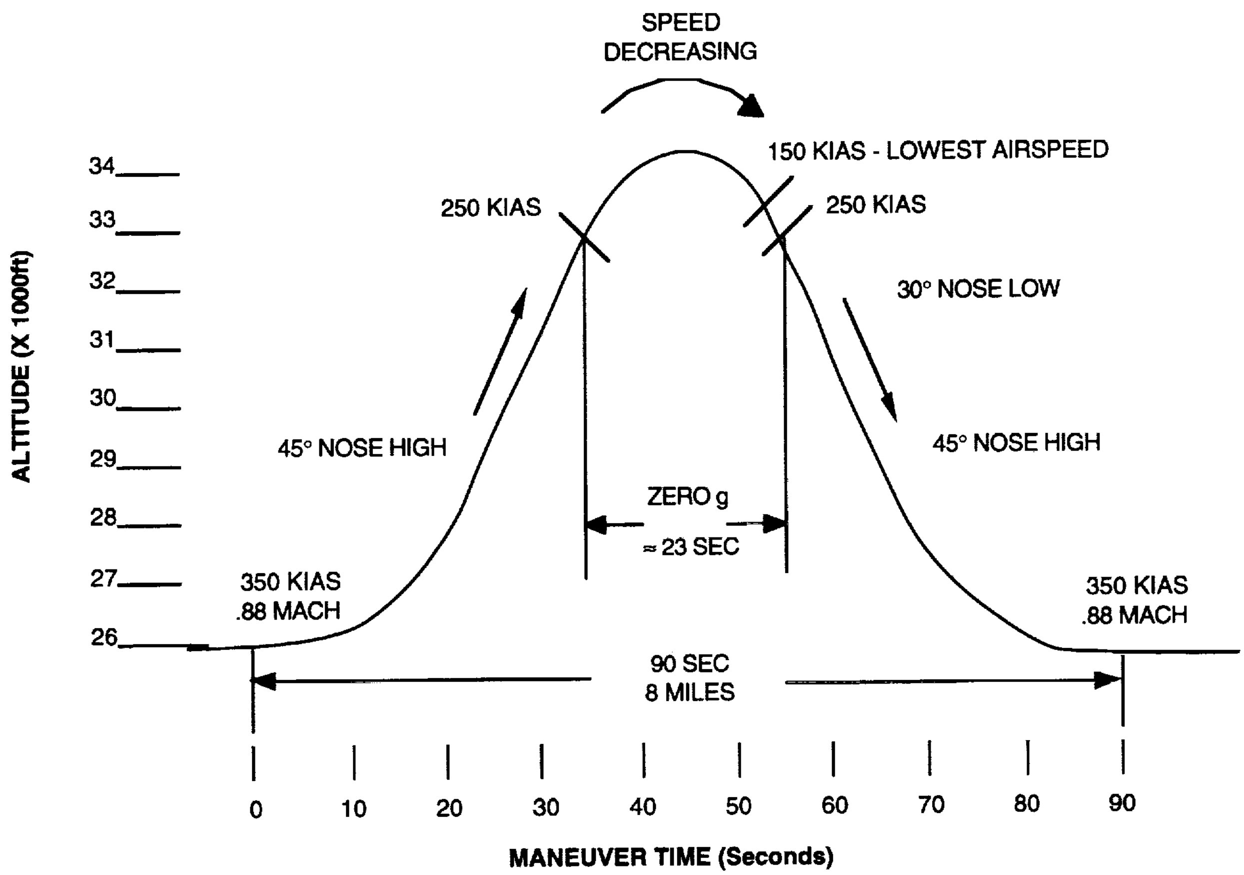

Figure A-1. Parabolic profile used with KC-135 micro-gravity flights.

Information supplied by the JSC Reduced Gravity Program.

APPENDIX B

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Figure B-1. Test stand.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	Apr/94	Technical Paper

4. TITLE AND SUBTITLE
Use of a Pitch Adjustable Foot Restraint System: Operator Strength Capability and Load Requirements

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Lyndon B. Johnson Space Center
Houston, Texas 77058

8. PERFORMING ORGANIZATION REPORT NUMBERS
S-764

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
TP-3477

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
unclassified/unlimited
Available from the NASA Center for AeroSpace Information
800 Elkridge Landing Road,
Linthicum Heights, MD 21090, (301) 621-0390
Subject category: 54

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The zero-gravity environment creates a need for a proper human body restraint system to maintain a comfortable posture with less fatigue and to maximize productivity. In addition, restraint systems must be able to meet the loading demands of maintenance and assembly tasks performed on orbit. The Shuttle's primary intravehicular astronaut restraint system is currently a foot loop design that attaches to flat surfaces on the Shuttle, allowing for varying mounting locations and easy egress and ingress. However, this design does not allow for elevation, pitch, or foot loop length adjustment. Several prototype foot restraint systems are being evaluated for use aboard the Space Station and the Space Shuttle.

The JSC Anthropometry and Biomechanics Laboratory initiated this study to quantify the maximum axial forces and moments that would be induced on a foot loop type of restraint while operators performed a torque wrench task, also allowing for angling the restraint pitch angle to study yet another effect.

Results indicate that the greatest forces into the torque wrench and into the foot restraint system occur while the operator performs an upward effort. This study did not see any significant difference in the operators' force due to pitch orientation. Thus, in a work environment in which hand holds are available, no significant influence of the pitch angle on forces imparted to the restraint system existed.

14. SUBJECT TERMS	15. NUMBER OF PAGES
restraints, optimization, human factors engineering	37
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclassified	unclassified	unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std. 239-18
298-102